

SOLAR DESALINATION-EFFECT OF CEMENT ABSORBER IN DOUBLE SLOPE SOLAR STILL

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ABSTRACT

Performance analysis of two segment “V” type solar still with cement block absorber is presented in this paper. The internal heat transfer modes are studied. The efficiency of the still is estimated in two ways. The overall efficiency of the still is 20% without cement blocks and 24% with cement blocks. Heat absorption property of cement is used for better output. The efficiency of the still, variation of internal heat transfer, variation of distillate yield are presented. The experimental properties of the still is estimated and compared under similar climatic conditions. The solar still experimentally tested on typical summer days in Coimbatore (11°.00 N, 77°.00 E), in particular, and India’s climatic conditions. Hourly inner as well as the outer glass temperature, ambient air temperature and solar radiations were recorded during the sunny days.

KEYWORDS: Solar Still, Fresh Water, Glass, Cement Block

INTRODUCTION

Fresh water is an immediate need for human life as drinking water purpose. Solar distillation plays an important role in the potable water production for arid and semi arid regions over the world. The 97% of available water sources are saline and include harmful bacteria and 2% is frozen in glaciers and polar ice caps. Hence, only 1% of the world's water is useable for drinking and domestic utilities [1]. Single slope basin type solar still showed that, the daily distilled water output from the still ranged from 2.8 L/m²/day to 5.7 L/m²/day and well known for its simplicity and cost effectiveness [2]. Whatever be the still methods, the main focus is the temperature difference between the water in the basin and glass cover as the temperature gradient control the rate of condensation on the glass cover. Several methods were proposed such as the use of an external condenser and mixing a dye with the water in the basin [3]. Both stills resulted in increased distillate yield but not without drawbacks. The use of an external reflector required an electric power supply and the effect of dye; the distillate quality has not been properly addressed. Taj et al., [4] have studied the performance of a single basin solar still coupled with flat plate collector. The average distillate yield for this type of still has been found. A transient analysis was made for a double slope single basin solar still by kumar and Tiwari [5]. The methods to enhance overall efficiency of a conventional basin type solar still by photocatalysts with different semi conducting oxides likes CuO, PbO₂ and MnO₂ were analyzed by Patel [6]. The results show that metal oxide not only improved the efficiency of the process but the rate of production of desalinated water. Bilal et al., [7] have studied variation of distillate water productivity using different absorbing materials. The experiment was performed in a single basin solar still with double slopes and an

effective area of 3 m^2 . Black dye was the best absorbing material used in terms of water productivity. Optimization of the orientation for a higher yield of a solar still was carried out in terms of the glass cover inclination by Singh [8]. The effect of water depth on the hourly instantaneous and overall thermal efficiency along with the internal heat transfer coefficient was also studied. Selvakumar et al., [9] have studied performance analysis of “V” type solar still using charcoal absorber and reported an approximate increase of 6% efficiency on comparative scale study. The main attractive of these types of still is a converging water collection at the centre of the still, thus one channel water collection without hindrance. Toure and Meukam [10] have made theoretical and experimental investigation for a solar still in climatic conditions in Abidjan. The results showed that the thickness of the glass cover has no effect on the production. The relative difference between the experiment and the theory was 5% for temperature, and 15% for productivity.

In the present work, an optimum water depth of 1 cm is maintained inside the still [11] for maximum yield rate. Cement blocks of volume 8 cm^3 have been placed inside the still at regular intervals of distance. A comparative study on performance of still with cement blocks and without cement blocks have been carried out. It has been observed that there is a significant improvement in the performance of the still using cement block absorber. A noticeable increase in the distillate output observed from experimental data; cement blocks release heat energy after sunset producing more distillate output. We report cement as good phase change material in solar distillation. The function of the internal evaporative heat transfer co-efficient of water temperature using cement block as absorber is also studied.

MATERIALS AND METHODS

A photographic view of double slop solar still and its sectional view are presented in Figure 1 and Figure 2 respectively. Cement blocks of dimensions $0.02 \text{ m} \times 0.02 \text{ m} \times 0.02 \text{ m}$ have been placed partially submersed inside the still at regular intervals of distance. 40 blocks/m^2 was the distribution and it covers 1.2 m^2 out of whole 1.5 m^2 area of still. The basin has been made by mild steel. Length and breadth of the still is given as 2.00 m and 0.75 m respectively. Bottom and sides of the still were painted black for good absorption of solar radiation. The water storage basin of the still has been designed of area $2.00 \text{ m} \times 0.75 \text{ m} \times 0.10 \text{ m}$ and sufficient insulation provided underneath and sides of the still to prevent heat loss. An inlet pipe of $\frac{1}{2}$ inch has been used for pouring water into the still. Heat loss is reduced by providing a wooden case. The inter space between still and wooden case has been filled with glass wool to ensure minimum heat loss. The top cover of the still has been made by glass thickness of 3 mm. Bushes were provided at each corner for perfect seating in surface. The two glass covers are joined in the middle by using chemical adhesive without any air leakage. Water collection channel has been provided at the centre of solar still. An inward slope is maintained on both sides of the still to bring the condensate water to central water collection channel. A 2° slope has provided to the water collection channel for smooth outward flow of distillate water. An outlet pipe of $\frac{1}{4}$ inch has been provided to collect the distilled water from the water collection segment. Incident radiation is transmitted by the glass cover. A part of the transmitted radiation is reflected by the basin water. A small portion of heat generated leaks at the bottom through conduction. The remaining portion of heat is used to raise the temperature of water, which causes evaporation. A part of the incident radiation reflected and absorbed by the cement block partially submersed in water. The experimental study performed between 9.00 a.m. to 5.30 p.m. The basin was filled with saline water to a height of 1.50 cm. Calibrated Cu-Constantan thermocouples were used to measure the temperature. The air temperature inside the still (T_a), glass cover temperature (T_g), water temperature (T_w), solar radiation (W/m^2) and distillate output were recorded at regular intervals of time.

RESULTS AND DISCUSSIONS

Experiments were carried out in the month of January; 2013. The experimental study started from 9:00 to 17:30 hours and the data was averaged for 5 days replication. The basin of the stills has been filled with saline water to the optimum height. Saline water has been poured into the still in the early morning in every day. The still has been operated in the shadow free place. The internal heat transfer in the still from basin water to condensing cover can take place mainly by convection, radiation and evaporation.

The heat transfer inside the still takes place by free convection. This is because the actions of buoyancy force due to the variation in density of humid fluid that occurs on account of temperature difference in the fluid, the rate of heat transfer from the basin water surface to condensing cover can be found by [12]

$$q_{cw} = h_{cw} (T_w - T_g) \quad (1)$$

The coefficient h_{cw} can be found out from the following equation

$$h_{cw} = 0.884 \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9 \times 10^3 - P_w)} \right]^{1/3} \quad (2)$$

For a small cover inclination and large width of the still the water surface and cover are considered as parallel surfaces. The rate of radiation heat transfer from water surface to cover is given by

$$q_{rw} = h_{rw} (T_w - T_g) \quad (3)$$

The radiation heat transfer coefficient is given by

$$h_{rw} = \epsilon_{eff} \sigma \left[(T_w + 273)^2 + (T_g + 273)^2 \right] [T_w + T_g + 546] \quad (4)$$

$$\sigma = 5.669 \times 10^{-8} \text{ W / m}^2 \cdot \text{K}^4$$

$$\epsilon_{eff} = \left[\frac{1}{\epsilon_g} + \frac{1}{\epsilon_w} - 1 \right]^{-1}$$

$$\epsilon_g = \epsilon_w = 0.9$$

Evaporative heat transfer is given by

$$q_{ew} = h_{ew} (T_w - T_g) \quad (5)$$

$$h_{ew} = 16.273 \times 10^{-3} h_{cw} (P_w - P_g) / (T_w - T_g) \quad (6)$$

Efficiency of the system is given by

$$\eta = M L / H_s A t \quad (7)$$

Figure 3 shows the arrangement of cement blocks inside the still. Figure 4 shows variation of radiation with respect to time. It increases with time and reaches a maximum range between 12.00 PM and 2.00 PM and then decreases. Radiation received during this study has been recorded in the range of 400 W/m^2 to 1100 W/m^2 . Figure 5 and Figure 6 show variation of temperature for water and air respectively. The maximum temperature rise in water has been recorded as 63.4°C with cement block and 60°C without cement block. Comparison of water temperature show that still with cement block shows a significant steady state after sunset. Similarly the maximum observed air temperature was 60°C . During this study, the corresponding variation in ambient temperature has been in the range of 31°C to 37°C .

Figure 7 shows the productivity of the proposed solar still. The productivity of the still mainly depends on wind velocity, perfect insulation and ambient temperature. In our experimental technique all the main parameters have been maintained for achieving the high distillate yield. The efficiency of any solar still depends on the yield rate. In this experiment, the productivity has been recorded as $3.5 \text{ L/m}^2/\text{day}$ with cement block and $2.9 \text{ L/m}^2/\text{day}$ without cement block. The daily distillate yield rate starts with fewer amounts in the morning hours. The cause of this is the slow increase of water temperature. After some time the water together with air are heated gradually and water becomes warmer and production reaches maximum. From this point on, productivity starts to decrease gradually.

But still with cement block shows a steady state of distillate output. Figure 8 shows the variation of internal heat transfer of the still with respect to time. The heat transfer in solar still can occur in two modes i.e. external and internal heat transfer. The external heat transfer is governed by conduction, convection and radiation processes, which are independent of each other. This heat transfer occurs outside of the solar distiller from the cover, bottom and side insulation. The heat transfer within the solar distiller is referred to as internal heat transfer mode, which consists of convection, evaporation and radiation. The convective heat transfer occurs simultaneously with evaporative heat transfer and these two heat transfers are independent of radiation heat transfer.

The evaporative heat transfer has been found to be in the range of $11.52 - 345.81 \text{ W/m}^2$, the radiation heat transfer has been recorded in the range of $11.10 - 110.60 \text{ W/m}^2$ and the convective heat transfer has been found to be $0.87 - 46.21 \text{ W/m}^2$ with cement blocks. Figure 9 shows variation of efficiency with respect to time. Efficiency of still with cement block absorber is 24% and it show increase even after sunset. This is mainly due to heat energy released by the cement blocks. Efficiency of the still without cement absorber is 20% and it decreases after 5.00 p.m.



Figure 1: Photographic View of Solar Still

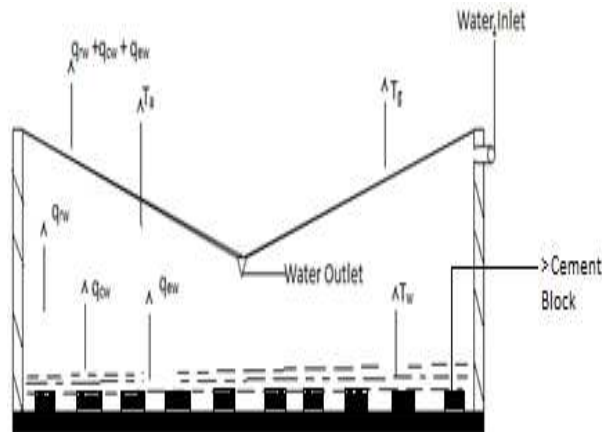


Figure 2: Schematic View of Solar Still



Figure 3: Cement Blocks Kept at Regular Intervals of Distance

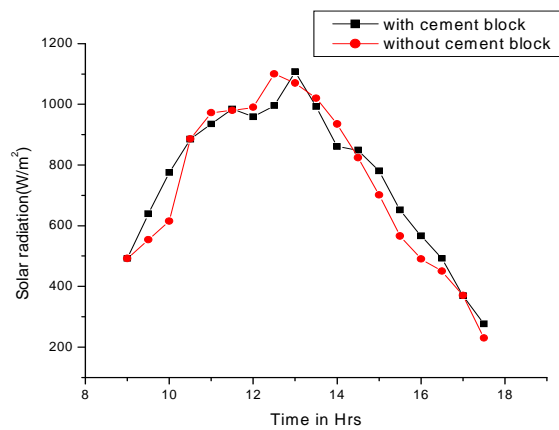


Figure 4: Solar Radiation

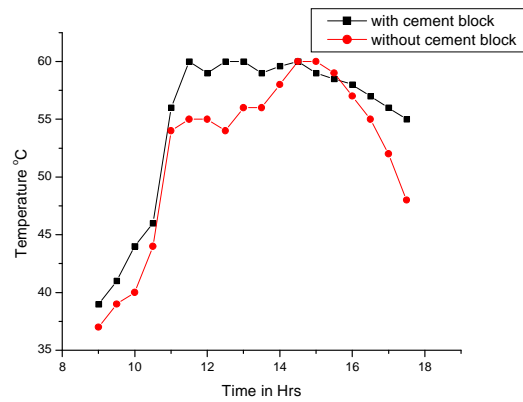


Figure 5: Variation of Air Temperature

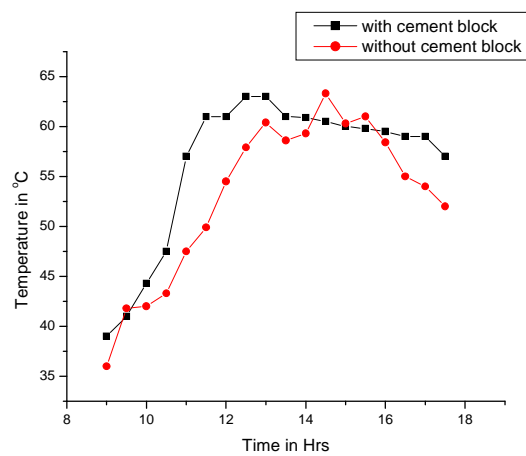


Figure 6: Variation of Water Temperature

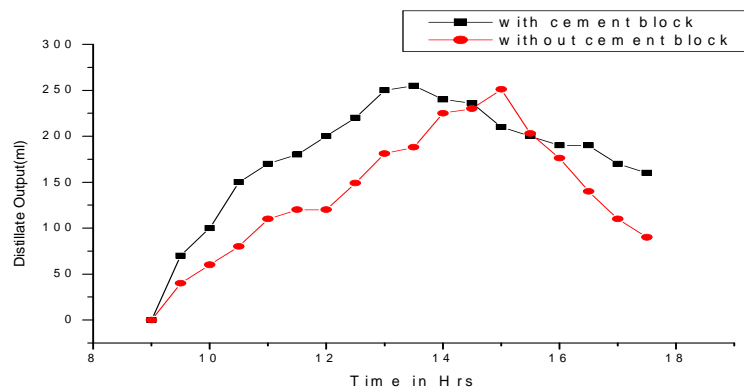


Figure 7: Distillate Yield with Respect to Time

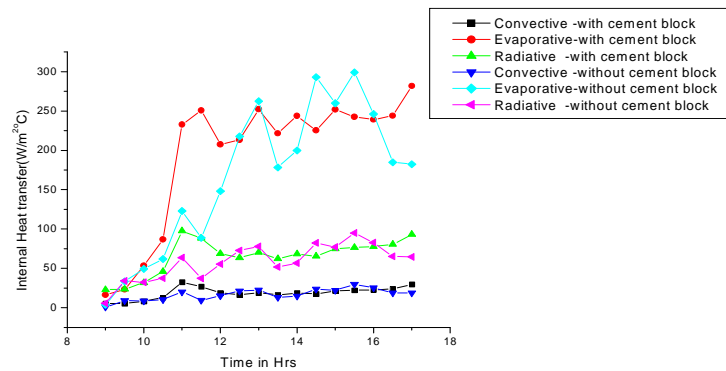


Figure 8: Variation of Internal Heat Transfer

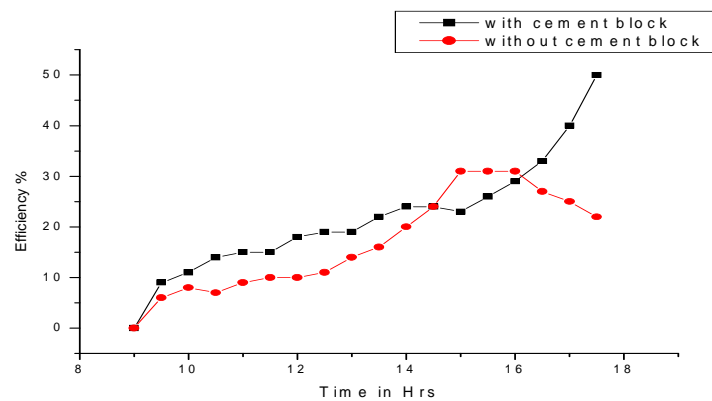


Figure 9: Variation of Efficiency

CONCLUSIONS

A simple method of enhancing solar distillation is discussed in this paper. A “V” type basin solar still has been fabricated and tested. The efficiency of the still has been calculated as 24% with cement block and 20% without cement block. The main advantage of the still is cement blocks placed inside the still releases heat after 5.00 p.m and the efficiency increases by 4%. High density structure of cement causes absorption of heat at the peak hours and it liberates the same after sunset. We report cement as good phase change material for solar desalination. This design is expected to provide the rural communities an efficient way to convert the brackish water into potable water. Producing fresh water by a solar still with its simplicity would be one of the best solutions to supply fresh water to villages and arid regions.

LIST OF SYMBOLS

- h_{cw} - Convective heat transfer coefficient ($W/m^2\text{ }^\circ C$).
- h_{rw} - Radiation heat transfer coefficient ($W/m^2\text{ }^\circ C$).
- h_{ew} - Evaporative heat transfer coefficient ($W/m^2\text{ }^\circ C$).
- L - Latent heat of vaporization (KJ/Kg).
- P_w - Saturation vapor pressure of water vapor at evaporation surface (Pa).
- P_g - Saturation vapor pressure of water vapor at condensation surface (Pa).
- H_s - Solar intensity (W/m^2).

- A - Area (m^2).
- M - Hourly yield of water (Kg).

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